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SONAR DISCRIMINATION ABILITY OF THE CALIFORNIA SEA LION, *ZALOPHUS CALIFORNIANUS**

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The three California sea lions (*Zalophus californianus*) on which the original active sonar studies were made (Poulter, 1963; Poulter, 1966) were borrowed by Stanford Research Institute (SRI) from the sea lion tank at the San Francisco Zoo. One of these was a three-year-old female that had been in captivity two years. When she was introduced into the SRI's anechoic tank for the first time, she spent an hour and a half exploring the entire tank in detail while clicking continuously. With a person's face close to the window in one side of the tank, she would approach to within about 6 inches of the window and click extensively.

The second animal was a two-year-old female that had just learned to accept dead fish and was the animal that used the long series of clicks that swept down in frequency over a 5000-cycle range (Poulter, 1966). The third animal was a five-year-old male that had been in captivity for four years and frequently barked under water without emitting any bubbles. When a person's face was close to the window of the anechoic tank, this animal would sometimes approach to within a few inches of the window and bark as many as 12 times without emitting any bubbles.

These animals were all shown to use an effective active sonar for locating

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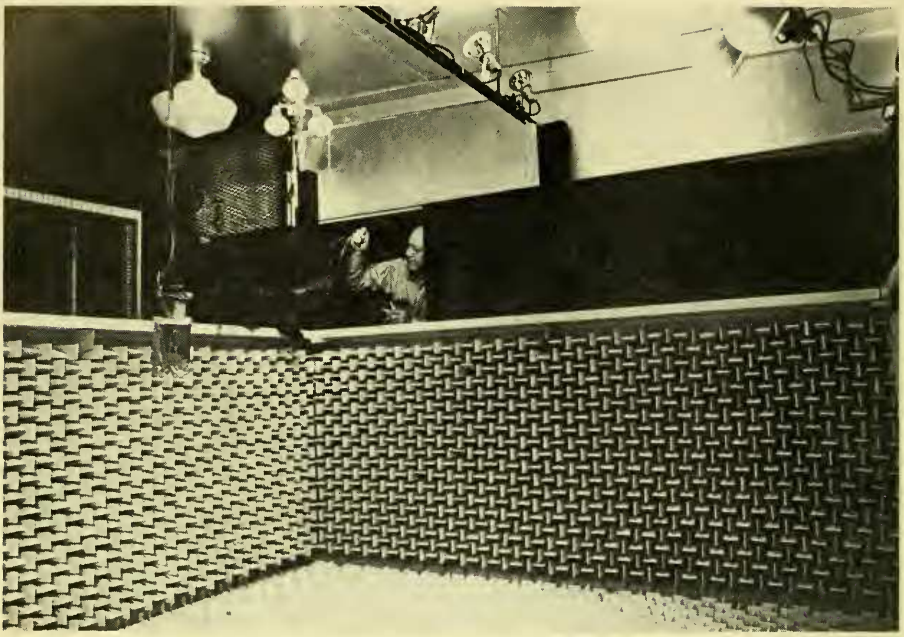

FIGURE 1. Anechoic tank in which discrimination tests were run.

pieces of fish and discriminating between horse meat or beef and fish in total darkness (Poulter, 1966).

To further study the ability of the California sea lion to discriminate between beef and fish, a male California sea lion named "Whiskers" was selected for this series of studies. Whiskers had been captured at an age of two years and had been in captivity at SRI's Biological Sonar Laboratory for about four months. (See fig. 1 for picture of Whiskers being given a fish on the edge of the empty anechoic tank.) During the four months in captivity and after he had learned to accept dead fish, he was usually fed individually by hand, with only an occasional single fish being thrown into the holding pen and pool containing about 12 to 15 animals, including four or five different species. In the scramble that occurred for these fish, the California sea lions—being the most agile—usually retrieved them or even caught them in mid air as they were thrown in.

The anechoic sea lion research tank (fig. 1) in which these experiments were conducted is located in a laboratory that can be darkened for experimental purposes. In fact, a piece of high-speed photographic film can be left in this laboratory for two hours with one-half covered and the other half exposed, with no detectable difference in the two halves when the film is developed. The anechoic characteristics of this research tank are such that the reverberation in the tank drops by 60 db. in 13.5 milliseconds for a decay rate of 4500 db./sec. For frequencies down to 300 Hz., the absorption coefficient of the walls is 0.925. So far as the authors are aware, this is the first anechoic research tank to achieve such effective performance characteristics at such low frequencies, whether in bioacoustics research or in underwater acoustics in general.

When Whiskers was placed in this anechoic tank with the lights off for the first experimental feeding period, monitoring did not reveal any large amount of clicking and only an occasional piece of fish would be picked up before it drifted to the bottom and became inaccessible in the acoustical wedges. When the lights were on, he would retrieve the fish quickly with the emission of very few audible clicks. For the next two weeks, Whiskers was fed primarily in total darkness, with the fish being lowered into the tank by a piece of silk fish line threaded through the tail of the fish with a knot in the end of the line so that it could be pulled through easily. This line was then held by hand so that the operator could detect any contact and know when the fish was taken. By the end of the second feeding period, Whiskers was clicking most of the time and retrieving the fish after a delay of only a few seconds.

During this period, the characteristics of Whiskers' clicking signals were studied by listening to the monitoring loudspeaker and through sonagrams and other analysis techniques. For quick monitor recordings and playback after some test periods, a Uher 4000 report recorder was used. However, all recordings made for sound analysis were recorded on the Model 101 Pemco recorder (having a flat frequency response from 100 Hz. to 100 kHz.).

The targets used for this training period were thawed herring ranging from 6 to 12 inches in length. All fish used for training and tests were whole and the animal was fed to satiation. The procedure of training and testing, combined with the opportunity to enter the larger interior tank, seemed to be adequate to arouse the interest and curiosity of the animal so that food deprivation was not found necessary. In fact, during both the training and testing period, as it became satiated, it would retrieve additional fish and then drop them and return to its starting point to await the signal to start the next run. The cue to start the run was a 1500-Hz. pulse on an underwater loudspeaker. A careful examination of Whiskers' clicks showed certain characteristics that had not been observed for any other California sea lions previously studied.

This was the first study of which the authors are aware in which there was a correlation in the animal's clicking signals and the type of target on which it was echoranging. This was first observed while experimenting with fish of different sizes. When a very small fish was suspended in the water in total darkness, the monitored clicking appeared to have two distinct frequencies. Sonagrams of these signals confirmed this observation, with the lower frequency ranging between 500 Hz. and 1000 Hz. and the upper frequency between 2500 Hz.

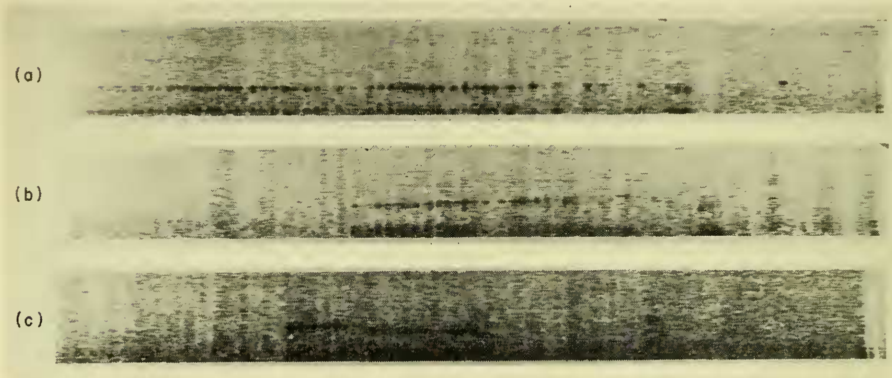

Figure 2. Sonagrams of double frequency echoranging signal used on small fish.

and 3500 Hz. (fig. 2). When no fish were being introduced into the tank which was still in total darkness, Whiskers produced much louder clicks and at a more nearly uniform rate and sonagrams of these signals also show a much broader frequency range (fig. 3a, b, c) bordering on a white noise.

Whiskers' approach on a target in the anechoic tank was invariably accompanied by a drop in signal strength of sometimes as much as 20 db. and associated with a grouping of the clicks into short bursts of less than one second duration, sometimes forming a pattern on the sonagram (fig. 4). Therefore it was often possible to determine when he started his approach by monitoring his clicking.

When Whiskers was waiting for a fish to be put in the water and the signal to start the run, there would frequently be periods of several seconds when there would be no clicks. This provided an opportunity to conduct another experi-

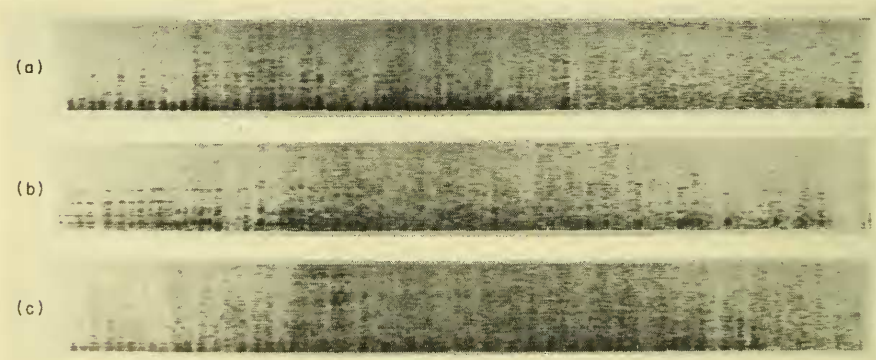

Figure 3. When searching for a target, a rapid uniform clicking note is used.

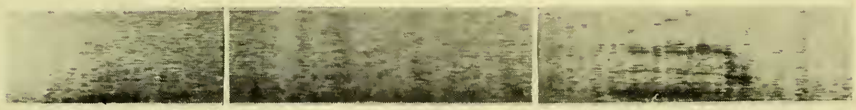

FIGURE 4. After target is located, the clicks are grouped into short duration bursts as the subject approaches the fish.

ment: to determine if fish could be lowered into the water when Whiskers was not clicking without their being detected. The length of time that elapsed after lowering the fish into the water and before he started to click again strongly suggested that he was not aware that the fish had been introduced. We, of course, do not know when he would have started to click again if the fish had not been introduced. This was further suggested by the fact that on some occasions there would still be several seconds delay after he resumed clicking before he started his approach. The series of clicks would always terminate just prior to or simultaneously with his reaching the fish. A dim light was employed before introducing the fish to insure that the sea lion was back in the starting position and not near the point where the fish was to be introduced for the next run.

Investigators have suggested that the sea lion searches around in the tank at random until it runs into the fish. Therefore, in order to determine the exact path of approach, four hydrophones were mounted in the research tank—two near the surface in two opposite corners of the tank and two near the bottom in the other two corners of the tank.

To determine the exact path taken by the sea lion as it approached the fish, the animal's clicks were then recorded on four channels of magnetic tape from which triangulation measurements were made. In all paths thus plotted, the path of approach was close to the most direct, both horizontally and vertically. In no case did the animal dive deeply and approach the fish from below, as has been shown by Schusterman to be the case for visual approaches, particularly in dim light. After two weeks of training, Whiskers was retrieving the fish on 100 percent of the runs even though they were in a corner of the tank or so close to the acoustical wedges on the walls or bottom of the tank that they would be outside of any random swimming pattern.

With the lights on, Whiskers was then introduced to pieces of lean beef for the first time which he rejected completely. The beef was first offered to him in air, and he approached close enough to touch it and then immediately turned away. It was then held under water; he again approached it but would not take it in his mouth and again turned away.

Two targets, a fish and a piece of beef cut to about the same size as the fish,

FIGURE 5. Short duration bursts terminating in an up-sweep in frequency.

were attached to two strings with spring paper clips so that they would pull off easily. (On two occasions in order to make the dimensions of the beef targets more closely resemble that of the fish, two thin pieces of beef were stitched together.) The targets were attached to opposite ends of a stick which separated them by 15 cm. to 100 cm. As before, a dim light was used to ensure that Whiskers was at a distance from where the targets were to be introduced. After this light was turned off, the two targets were introduced simultaneously and at random orientation in the tank and Whiskers was given the signal to start the run. Three different types of contacts were recorded: First, a vibration of the string such as might be caused by the animal brushing against the fish or string. Second, a slight pull on the string, indicating a more direct contact or that his flipper may have struck it. And, third, a sudden jerk on the string, caused by the animal's actually pulling the fish or the beef off the end of the lines. In most cases when the fish was retrieved, the string holding it was pulled in the direction that Whiskers was traveling when he contacted it.

During the first day's discrimination tests, a total of 31 runs were made with a score of 2, 2, and 27: The animal apparently touched the meat or the string twice; produced a slight pull on the string twice, but not enough to pull off the beef target; and actually retrieved the fish on 27 approaches. In no case was the beef pulled from the paper clip holding it. The bursts of signals used on these discrimination runs almost invariably terminated in a small upsweep in frequency just before reaching the target, which was easily detected by monitoring and confirmed from sonagrams (fig. 5). This was reminiscent of the technique of using a sweep frequency to discriminate between a whale and a submarine target.

In all, 1196 runs were distributed over 31 test periods. Although on some days no tests were made, the animal was only fed during tests. In no case was there more than one test period in a single day.

The elapsed time to retrieve the fish after the target was lowered into the water and the cue was given to start the run was about 5 to 8 seconds, with it frequently being less than 5 seconds.

SUMMARY

A total of 1196 runs were made in 31 test periods in which Whiskers was asked to discriminate between fish and beef targets with or without other targets being present. When actual test runs were started, six different types of contacts were recorded.

- *A Contacts* (*Beef A or Fish A*): Any vibration of the string, which might be caused by Whiskers brushing against the target or string as he swam by.
- *B Contacts* (*Beef B or Fish B*): A slight pull on the string, which might be caused by a more direct contact or by the target carefully being taken in his mouth.
- *C Contacts* (*Beef C or Fish C*): A sudden jerk on the string, indicating actual retrieval of the target from the paper clip without previously making an A or B contact.

Because of the considerable time involved in tracking the path of the animal through triangulation recordings and calculations, a much simpler technique was tried. It had been observed in some earlier work that if two hydrophones are placed about five feet apart in the anechoic tank with the output from each being connected to separate receivers of a pair of headphones, an excellent binaural effect is produced.

This, therefore, suggested the possibility of following Whiskers binaurally with two hydrophones spaced five feet apart along one side of the tank. Such an installation was made and it was immediately apparent that it would not work. As Whiskers was going from one end of the tank to the other, the binaural effect placed him at the end of the tank toward which he was traveling; but just as soon as he turned around and faced in the opposite direction, the binaural effect placed him at the other end of the tank. In other words, the binaural effect placed him at whatever end of the tank he was facing regardless of where he was in the tank. The only conclusion that can be drawn from this is that the sound of his clicking is concentrated in a beam directed more or less forward.

In order to get some measure of the width of this sonic beam, four hydrophones were placed in the tank in a line normal to his line of approach on the targets. These four hydrophones plus the fish and beef targets in effect made an array of six targets which, from the results of his discrimination between fish and beef, did introduce some confusion. Three other target displays were used in these tests.

In a total of 40 runs, the fish and beef targets were placed in close proximity to the acoustic wedges of the tank. In a total of 61 runs, the targets were out

Table I.

	6 Targets	Targets Against Tank Wall	Laminated Beef Target	2 Targets	Total	Percent
Fish A + B						
C	85	31	32	835	983	82.2
Beef A + B	39	9	29	135	212	17.8
C					1	
Totals	124	40	61	971	1196	100.
Percent Correct	68.5	77.5	52.4	86.0	82.1	

away from the walls of the tank, but the beef target was made up of two thin pieces of beef stitched together to form a laminated beef target. On the remaining 971 runs, the targets were a fish and a single piece of beef cut to approximately the same size and shape as the fish.

The binaural experiments demonstrate for the first time that the underwater signals of the California sea lion are directed generally forward, and the relative signal strength as recorded by the line of four hydrophones normal to his path of approach toward the targets shows that this is a very broad beam.

The data given above show that all contacts with the fish were C contacts, whereas all but one of the beef contacts were A or B contacts. On a high percentage of the C contacts, there was a pull on the string in the direction that Whiskers was traveling when he retrieved the fish. Since this horizontal effect did not occur on the A and B contacts, it is possible that the contacts were accidental as he passed rather than his taking the fish in his mouth to determine what they were. The fact that there were no A and B contacts with the fish is strong evidence that Whiskers knew what he was approaching before he actually contacted it. In the case of the laminated beef targets, the performance was completely chance. This, however, does provide a clue as to what difference in structure might have been causing the difference in the echo on which he based his discrimination. Even though the herring does have an air bladder of sorts, an inspection of many frozen fish shows that in most cases this bladder is collapsed. However the folded or laminated piece of beef might more closely resemble the cross section of a fish than would a homogeneous single piece of beef.

The fact that all of the fish contacts in those runs were a laminated beef target was involved were C contact (52.4 percent) and all of the beef contacts were A and B contacts (47.6 percent) cannot be explained on a basis of an accidental contact with the beef target but does suggest that a more careful inspection at close range took place. There is still some question as to whether Whiskers could have actually taken the beef targets into his mouth without pulling them free from the paper clip.

The presence of the four additional targets in the form of hydrophones apparently did cause slight confusion to the animal, but the 68.5 percent C contacts is certainly significant. The placement of the target against the tips of the wedges of the tank walls (with 36 wedges 2 inches square at the base and 6 inches high per square foot) appears to have produced less confusion than does the 4 hydrophones as the percentage of Fish C contacts was 77.5 percent.

On the other hand, if Whiskers had only the two targets placed away from the walls of the tank, his percentage of Fish C contacts would be 86 percent as against 14 percent Beef A and B contacts. The 14 percent A and B contacts with the beef is consistent with his approach from his starting point at one end of the tank and the completely random orientation of the two targets, for in about 14 percent of the runs he was required to swim around the beef to get at the fish. This would indicate that he made no attempt to avoid the beef as he passed by. Therefore a more realistic appraisal of the data would indicate that a more nearly correct percentage of correct choices would be somewhere between the 86 percent, and the ratio of Fish C contacts to the Beef C contacts is 99.9 percent.

These studies have shown for the first time that the underwater sounds of the California sea lion are directed in a broad beam and generally forward. They have shown for the first time a direct relation in cause and effect between the signals emitted by the sea lion and the target presented to it, which further confirms its use of an active sonar. The studies have demonstrated that the sonar discrimination ability of the California sea lion is nothing short of phenomenal.

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